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ANALYSIS OF BALLISTIC CALIBRATION DATA AND GOVERNMENT/CONTRACTOR CEP TEST DATA WITH RESPECT TO THE AN/TPQ-27 CONTRACT INCENTIVE FEE DETERMINATION

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Analysis is performed on the adequacy and appropriateness of the methods and analytical techniques used by NWL, Dahlgren, Va., in establishing the ballistic characteristic of the Practice Bomb Mark 76 with lug on the basis of October/November 1972 test drops. AN/TPQ-27 CEP test results are also analysed with respect to potential system errors which could lead to observed bomb range discrepancies. On the basis of these analyses it is concluded that the source of the bomb range discrepancy is not associated with the Ballistic calibration but with the AN/TPQ-27 system. Possible sources of system errors are identified.

SUMMARY. The purpose of this study is to investigate the adequacy and appropriateness of the methods and analytical techniques used by The Naval Weapons Laboratory, (NWL) in establishing the ballistic characteristics of the Practice Bomb MARK 76 with lug, on the basis of October/November 1972 test drops as discussed in reference (a). A further purpose is to investigate the AN/TPQ-27 CEP test results with the goal of identifying potential sources of system errors to explain calculated bomb range discrepancies.

On the basis of the analysis performed, it is concluded that the source of the bomb range discrepancies is not associated with the specification of the ballistic characteristics of the bomb but with the TPQ-27 system. The nature of the system errors appears to be test condition altitude related and possible sources of error have been identified. A specific identification of the errors in the system will require further study of the TPQ-27 system and associated software, and/or further operational testing using the revised ballistics.

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I. INTRODUCTION

The purpose of this study is to resolve, if possible, the reason or reasons for the computed difference in bomb range (i.e., the bomb range derived from the ballistics used in the Government/Contractor (G/C) CEP tests minus the bomb range as established by NWL in ballistic calibration (BC) tests).

The argument for the government is that this bomb range discrepancy (BRD) is real and that the G/C CEP test bomb ranges always exceed the revised bomb ranges derived by NWL (see Table 1). Hence, it is claimed that since the BRD is not reflected in the G/C CEP test data, there are system errors in the AN/TPQ-27 system which have been masked by the selection of form factors used in the G/C CEP tests. The contractors claim is that there are no such system errors, that they do hit close to the target and hence the error must be on the part of NWL in establishing bomb range.

The following report will investigate both sides of this question utilizing both the NWL data from the BC tests and the G/C CEP test data. The following topics will be considered:

1. The adequacy of the analysis methods used by NWL in establishing bomb range.

2. The adequacy of the analysis methods used by NWL in establishing bomb dispersion characteristics.

3. The accuracy with which the AN/TPQ-27 senses the position of the aircraft and the effect of the observed positional errors.

4. The possibility of software routine errors in the AN/TPQ-27 system.

II. INVESTIGATION OF BALLISTIC CALIBRATION METHODS AND RESULTS.

a. A Description of the Data Base Used by NWL in Ballistic Calibration. In order to establish ballistic parameters and bomb dispersion CEP specification to be used in evaluating the AN/TPQ-27 performance, 76 practice bombs were dropped (Reference (a)). Eight tests conditions were utilized (see Table 2a) ranging in altitude from 2000 feet to 30,000 feet, and in velocity from 300 NM to 500 NM. Sixteen of the 76 drops were eliminated because of insufficient or invalid test data, leaving a usable total of 60 drops. The number of drops at the various test conditions ranged from 4 to 11. For each drop the data base consisted of the observed bomb range, the observed deflection of the bomb from A/C track, the observed trajectory of the bomb, the observed time of fall, the atmospheric and meteorological conditions and the deviations, if any, from the established test conditions. The magnitude of errors in measured observed bomb range attributable to instrumentation, as described by Jim Mitchell, NWL, is minimal when compared to either bomb dispersion or the magnitude of the discrepancy in bomb ranges. This is supported in the BC test drop data by the small value of total variability in observed minus computed bomb ranges at test condition 1 (see Figure 1) which includes a component of measurement error. The effect of measurement errors which do exist would be to increase the specified CEP and hence improve relative G/C CEP test performance. The questions of sample size adequacy for establishing bomb range and bomb dispersion will be discussed along with the discussion of analysis methods below.

b. The adequacy of the Analysis Methods Used by NWL in Establishing Bomb Range. The method of establishing the bomb ranges corresponding to the various CEP test conditions is a two step procedure. The first step is to use the NWL test data as a basis for selecting a ballistic drag curve which models the observed relationship between ballistic drag and Mach number. The second step is then to use this ballistic drag model to determine the bomb range analytically for standard test conditions and atmosphere. The accuracy of this procedure depends upon the validity of the selected ballistic drag curve in the Mach number range of interest and the adequacy of the trajectory algorithm which computes bomb range under standard conditions and range. The authors have no statistical evidence with which to judge adequacy of the trajectory algorithm. In this report it is assumed such trajectory algorithms are adequate. In the following, we shall consider the techniques used in selecting the ballistic drag curve.

The aim of the ballistic calibration analysis is to find a single drag curve for which the calculated bomb range (CBR), using the trajectory algorithm and the observed test, atmosphere and meteorological conditions, is close to the corresponding observed bomb range (OBR) for each drop. Realizing that there is ballistic dispersion present in the OBR's an attempt is made to find a single drag curve for which the average OBR-CBR is close to zero at all 8 test conditions. The procedure to accomplish this is iterative: an initial drag curve is used to compute CBR for each drop, then on the basis of the signs and magnitudes of the average OBR-CBR for the 8 test conditions, a revised drag curve is selected and the CBR's are recomputed and again compared with OBR's. Because of the presence of ballistic dispersion it is unrealistic to expect to have average OBR-CBR zero at all 8 test

conditions simultaneously. Hence, judgment plays a role in determining when to stop the iteration procedure and no longer try to obtain a better ballistic drag curve. In the present case (see figure 1) when the iterative procedure was stopped, except for test condition 1, the average OBR-CBR was within 1.5 standard error (S.E.) of zero and in 4 of the 8 test conditions within 1 S.E. of zero (see table 2b). In addition, in the present case, the average value of OBR-CBR is negative for 4 of the 8 test conditions and positive for the other 4. Moreover, the signs and magnitude of these averages do not seem to be related to test altitude or velocity.

To address the question of whether the average OBR-CBR from the 8 test conditions are typical of what might be observed if the selected drag curve were the true drag curve, consider the following: Under the assumption that the selected drag curve is the correct one and hence expected (OBR-CBR) = 0 and that the individual OBR-CBR are normally distributed, then at any test condition, $t = (\text{Ave(OBR-CBR)})/(\text{SE(OBR-CBR)})$ has a t-distribution with n degrees of freedom where n is sample size. Since $E(t) = 0$ and $VAR(t) = n/(n-2)$, it follows that $X = t/(n/(n-2))^{\frac{1}{2}}$ has $E(X) = 0$ $VAR(X) = 1$. If we so transform the average (OBR-CBR) for the 8 test conditions we see that $\bar{X} = .02$ and $S_X^2 = 1.08$. (This computation is displayed in table 2b.)

The result that $\bar{X}$ is close to zero only reflects the success of NWL in selecting a ballistic drag curve which on the average, over the 8 test conditions considered, predicts the true bomb range. However, S_X^2 is also very close to the theoretical value of $\sigma^2 = 1$, a measure quantifying the degree of variability expected in average (OBR-CBR) if the ballistic drag curve was the correct one and hence predicting each of the 8 individual bomb ranges

correctly. This statistical evidence thus suggests that the deviations of average (OBR-CBR) from zero are for the most part due to sampling variation and not inaccuracies in the ballistic drag curve.

The question remains as to whether the sample size of 60 with 8 test conditions is adequate for selecting a drag curve. Since this process is based on judgment, and because of the different and unknown distributional properties of ballistic dispersion at the 8 test conditions, no analytical examination of adequacy of sample size is available. Clearly, these 60 observations at the 8 test conditions should lead to a more reliable result than if all 60 observations were at a single test condition. In general, statisticians would conclude that 60 is an adequate sample size for obtaining a reasonable estimate of a population mean. In light of the wide variety of conditions the 8 test conditions represent, the sample size seems quite adequate. As a result it is concluded that the selected ballistic drag curve is very probably a close approximation to the true drag curve and consequently the calculated bomb range is very probably close to the true bomb range.

c. <u>The Adequacy of the Analysis Methods Used by NWL in Establishing Bomb Dispersion Characteristics</u>. The estimates of bomb dispersion at the various test conditions were calculated in a manner relatively insensitive to errors made in selecting the ballistic drag curve. The analysis was based on the assumption that the ballistic dispersion errors are circular normally distributed with deflection errors measured with respect to aircraft track (after correction for deflection wind effect) and with range error measured from the average OBR-CBR. This calculation is appropriate, assuming wind effects can be accurately accounted for and it is more appropriate to lose a degree of freedom by estimating the mean of the range error distribution from the

data than it is to assume this mean is zero. (The latter is equivalent to assuming that the CBR was the true bomb range.) The resulting bomb dispersion estimates (table 2a, column 1) with 2N-1 degrees of freedom, where N is the number of bomb drops within a test condition, are then unbiased estimates of the bomb dispersion centered on the true aiming point. True aiming point is that point at which the bomb would impact if OBR was equal to TBR. If, however, the CBR is not the true bomb range this error will cause the true aiming point to be displaced from the target by an amount equal to CBR-TBR. In such a case the estimated bomb dispersion will underestimate the true bomb dispersion measured relative to the target. Thus, to take into account any differences between TBR and CBR in calculating bomb dispersion estimates for use in CEP tests of the TPQ-27, it is appropriate to measure both deflections and range dispersions errors from mean zero. Such estimates are contained in table 2a, column 4. Ninety per cent confidence intervals based on the X^2 distribution are included in columns 3 and 6 of table 2a for the bomb dispersion estimates in columns 1 and 4 respectively. In addition, the estimate of bomb dispersion based on the median radial error derived from range and deflection errors measured from mean zero are given in column 7 of table 2a. Confidence intervals were not obtained for bomb dispersion based on this estimate because of the small sample sizes involved. The median range error calculation does not require the assumption of circular normality, which, on the basis of the present data, does not appear to be a valid assumption. However, table 2a shows the three measures of bomb dispersion to be comparable in value for all test conditions and it is difficult to make a strong case for selecting one over the other. The above, however, does not explicitly

answer the question of the adequacy of the sample size used in the ballistic calibration tests and resulting bomb dispersion estimation. To examine the sensitivity of the overall specified CEP and hence CEP bombing ratio to errors in computing bomb dispersion, the upper confidence limit from column 6, table 2a, is used in obtaining revised specified CEPs in the manner specified in reference (b). In these calculations the adjusted CEP increases by a maximum of 10%. If these upper 90% confidence limits were used as measures of bomb dispersion in computing specified CEP, the resulting increase in average CEP bombing ratio would be from .80 to .84 (see table 7). (These calculations are based on specified CEP and CEP bomb ratio data in reference (b).) The relative insensitivity of specified CEP to changes in bomb dispersion is due to a relatively large portion of specified CEP resulting from other budgeted dispersion (see table 8). Since it is unlikely that the value of ballistic dispersion CEP has been substantially underestimated in every test condition, it appears that the sample sizes utilized were adequate for the purposes of establishing ballistic dispersion CEP.

We may consider this sample size adequacy problem in another light. It seems reasonable to expect some functional relationship between bomb dispersion and the velocity and altitude of the aircraft at drop. If sample sizes are adequate to estimate bomb dispersion at each test condition, then a plot of estimated bomb dispersion against drop altitude and velocity should show a reasonable amount of regularity corresponding to the above suggested functional relationship. In figure 2, estimated bomb dispersion (column 4, table 2a) is plotted against drop altitude with velocity at drop specified adjacent to the plot. Figure 2 suggests the bomb dispersion estimate is high at 20,000 feet, 500 NM and possibly low at 20,000 feet, 350 NM. However, in neither case does it appear that the estimated value of bomb

dispersion would deviate enough from the true value to significantly change the specified CEP.

In summary it may be concluded that errors made in arriving at bomb dispersion due to relatively small sample sizes cannot have a significant effect on the specified CEP and hence on CEP bombing ratio. The range adjustment due to the discrepancy between the bomb ranges calculated from the NWL-developed ballistic model and the ballistics utilized in the G/C CEP testing has a significant effect on the CEP bombing ratio. Hence, errors in the bomb ranges derived from the NWL ballistics could bias the CEP bombing ratio. However, as stated above, it does not appear that such errors exist of a magnitude comparable to the discrepancy in bomb ranges.

III. Investigation of Government/Contractor CEP Test Data.

We have concluded that, although there may be small errors in computing bomb range due to minor inaccuracies in the selected ballistic drag curve, the magnitude of these errors in general cannot account for the discrepancies suggested between the bomb ranges derived from the revised ballistics and the ballistics used in the government/contractor CEP tests. Thus, given that this bomb range discrepancy (BRD) does exist but is not reflected in the impact positions of the bombs, there must be some feature or features of the AN/TPQ-27 system which compensated for these BRD's. In all test condition-form factor combinations except 9c (for which the form factor = 1) the utilized bomb range exceeded the revised bomb range. Thus, in order for a bomb to hit near the target, the AN/TPQ-27 must compensate in some manner which allows the aircraft to get closer to the target before release than it would if the system were error-free. Possible compensating features of this type are:

1. the TPQ-27 senses the aircraft further from the target than it actually is;

2. the TPQ-27 senses the aircraft lower in altitude than it actually is;

3. the TPQ-27 senses the aircraft's velocity is less than it actually is;

4. the TPQ-27 senses the time of release prematurely;

5. the TPQ-27 senses range, altitude and velocity correctly but internal software errors produce effects equivalent to 1, 2 and/or 3;

6. the bomb range computation algorithm tends to deflate bomb range, or

7. the effect of ballistic wind is not properly incorporated into the bomb range computation.

One of more of the above system errors, along with the observed mean miss distances, could account for the bomb range discrepancies. The available data base does not allow an investigation of all the suggested possible features. Features 1 and 2 will be extensively considered along with impact distances; the other potential causes will be investigated to the extent possible and the results discussed.

a. Investigation of Range and Altitude Errors.

To investigate the possibility that range and altitude errors are such as to compensate for the bomb range discrepancy, the following approach was taken. Due to its closeness to the aircraft at time of release, the position and direction of flight (aircraft track) as given by the FPS-16 radar were accepted as a standard with respect to which the TPQ-27 position errors were measured. In actual fact there are positional and directional errors associated with the FPS-16 data. These are assumed small with respect to the TPQ-27 errors when the latter is 50 or 100 NM from the target. Both radars appear to have negligible errors when they are within 10 NM of the aircraft. The data base used in this analysis consisted of 185 bombing runs as described in table 3. The selection of this set of runs, out of all possible, was based on the availability of valid positional data for both radars as well as impact data with the following exceptions. Two runs which resulted in improper ballistic flights (as characterized by very large (>1500 feet) impact misses) were excluded.

Utilizing this data base ΔX, ΔY, ΔZ representing East-West, North-South and altitude positional errors respectively were calculated for every run by the following equations: $\Delta X = X_{27} - X_{16}$, $\Delta Y = Y_{27} - Y_{16}$ and $\Delta Z = Z_{27} - Z_{16}$ where the subscripts designate the radars. For test

conditions 14 and 17, Z_{27} was the test condition altitude because the forced altitude mode was being used. This data, averaged by test condition and by aircraft direction relative to the AN/TPQ-27 radar, is presented in table 4. By comparing the radar's positions of the aircraft relative to the target, the difference in range to the target, ΔR, and the angular difference from the 2 radar's directions of the aircraft to the target, $\Delta\theta$, are also calculated for each run and the averages presented in table 4. In addition, the average impact range miss (IRM) distance is recorded.

The data in table 4 suggest that there are positional errors in the AN/TPQ-27 data. We consider the question of whether these errors are within design tolerance and to what extent they affect bombing accuracy. Calculations show that in all cases the average horizontal and vertical errors do not exceed the 0.1 Mil allowable error in azimuth and elevation alignment. However, the altitude errors observed under conditions 9 and 10 exceed the 100 feet maximum allowable at 20,000 feet. A further look at table 4 suggests that the principal location errors are those associated with alignment bias. The existence of an alignment bias is detected in the calculation of the relative aircraft positions as given by the 2 radars and the relative ranges to the target from these positions. For example, in test condition 11, where the general aircraft track was 20 degrees (inbound) and 190 degrees (outbound) relative to true north, the TPQ-27 located the aircraft an average of 100 feet east and 28 feet north of the FPS-16's aircraft location. This deviation is essentially a displacement of 113 feet perpendicular to the aircraft track as the average range difference to the target from the 2 radar's aircraft locations is only 16 feet. Thus, under the assumption the

FPS-16 registers the true aircraft location, there appears to be an alignment bias in the TPQ-27 radar. The magnitude of the bias varies across test conditions but always appears to be present. As test flights were either oriented toward or away from the TPQ-27 position the bias did not affect aircraft to target range determination. If, however, flights were oriented perpendicular to the TPQ-27 radar beam, the alignment bias would result in an error in the calculation of aircraft to target range by the TPQ-27 system and as a result a corresponding range miss of the impact of the bomb on the ground.

The data in table 4 suggest that there are positional errors associated with the TPQ-27 system, but in general these errors are within the allowable tolerances. A question that remains is, "Are there biases or systematic errors in position which would compensate for the use of the incorrect drag curve as has been suggested?"

To investigate this, let us define CBR_i as the computed bomb range used in the $i^{\underline{th}}$ G/C CEP test drop. Thus CBR_i represents the distance the TPQ-27 sensed the aircraft was from the target at the time of drop. Also, define OBR_i as the observed bomb range between the actual location of the aircraft at the time of the $i^{\underline{th}}$ drop, as detected by the FPS-16, and the point of impact of the bomb. Thus OBR_i equals true bomb range TBR_i plus bomb dispersion range error ϵ_i. TBR_i cannot be computed because the true drop conditions are not available. A comparison between CBR and TBR can be made by the following computation (see figure 3):

$$CBR_i = OBR_i + \Delta R_i - IRM_i$$

$$= TBR_i + \epsilon_i + \Delta R_i - IRM_i$$

where CBR_i and OBR_i are defined above,

ΔR = range positioned error (positive ΔR indicates the aircraft was sensed to be located further from target than it actually was)

IRM = impact range miss (negative IRM indicates the bomb fell short of the target)

However, CBR cannot be compared directly with TBR since they involve different altitudes. To correct for this, let $CBR^* = CBR - \Delta Z^*$, where $\Delta Z^* \cdot K_j$, where in turn K_j is a constant expressing the additional horizontal bomb flight in feet for each foot of increase in altitude in bomb drop at the $j^{\underline{th}}$ test condition. The values of K were obtained from a sensitivity analysis of the effect of altitude on bomb range from certain velocities and base altitudes for the Mark 76 without lug. This data was provided by NWL and the values of K used are included in table 5, Appendix 1. Thus, CBR^* is an estimate of the computed bomb range which would have been used if an altitude error had not been made. Figure 3 depicts the geometry of these calculations. Thus,

$$
\begin{aligned}
CBR^* &= CBR - \Delta Z^* \\
&= OBR + \Delta R - IRM - \Delta Z^* \\
&= TBR + \epsilon + \Delta R - IRM - \Delta Z^* \\
&= TBR + \epsilon + \Delta BR
\end{aligned}
$$

The expression $CBR^* - TBR = \Delta BR + \epsilon$ was calculated for every bomb run and averaged over all data within a test condition-form factor combination.

Thus, assuming average ballistic dispersion range error is zero, the term $\overline{\Delta BR}$ is an empirical counterpart of the bomb range discrepancy suggested by NWL, in that it represents the difference between where the TPQ-27 thought the bomb was going and where it actually went. If the values of $\overline{\Delta BR}$ are of about the same magnitude as the suggested bomb range discrepancy, this is evidence that positional errors by the TPQ-27 combined with target misses account for this discrepancy. If, on the other hand, they are not of the same magnitude, their value may suggest other possible sources of error in the TPQ-27 system. The values $\overline{\Delta BR}$ and the data from which they were calculated are included in table 4.

Estimates of $\overline{\Delta BR}$ have 3 components of variability: the ballistic range dispersion and the variation due to errors in measurement of ΔR and ΔZ^* as a consequence of estimating the actual position of the aircraft at bomb release from the FPS-16 data. This variability is estimated for each test condition-form factor combination on the basis of the individual ΔBR's within a test condition. This variability is characterized by its standard error $SE(\overline{\Delta BR}) = [Var(\Delta BR)/n]^{\frac{1}{2}}$ and is recorded in table 4.

For comparison with suggested bomb range adjustments, $\overline{\Delta BR}$ is also recorded in table 1. A comparison of columns 3 and 5 suggests that position errors and target misses cannot account for the discrepancies in bomb range. Not only is the magnitude of $\overline{\Delta BR}$ not of the same magnitude as bomb range adjustment, there does not appear to be any systematic relationship. In particular, in test conditions 1, 3, 11 and 14, a proportion of the bomb range discrepancy is accounted for by positional errors and IRM, with the implication that the remaining discrepancy must be accounted for by other

TPQ-27 system errors. In test conditions 9a, 10 and 17 $\overline{\Delta BR}$ is negative, which suggests that other system errors must not only account for bomb range discrepancy, but for positional errors and IRM too. In test condition 9b, the value of $\overline{\Delta BR}$ more than compensates for the bomb range discrepancy so other system errors must correct for this over-compensation. In test condition 9c, which is the only case where the bomb range adjustment is negative, the value of $\overline{\Delta BR}$ suggests that there is an additional 199-foot error which cannot be accounted for by positional errors or IRM. Thus it must be concluded that while positional errors do exist and average impact range misses are sometimes quite large, these factors do not compensate for the suggested bomb range discrepancy.

In table 1, column 6, the differences between bomb range discrepancy and $\overline{\Delta BR}$ are tabulated. This quantity estimates the magnitude of the total effect of the TPQ-27 system compensation for the bomb range discrepancy exclusive of positional errors. These values are plotted in figures 4 and 5 against test condition velocity and altitude respectively. Except for the single point associated with test condition 9b, figure 4 suggests that the magnitude of the TPQ-27 system errors are altitude-related, whereas figure 5 gives little indication that system errors are velocity-related. In this context, other possible system errors will be considered.

b. Investigation of Other Potential System Errors.

Since positional errors appear to be mainly a result of alignment biases, the successive radar positions seem to be adequate to allow for accurate estimation of aircraft velocity. However, a constant or multiplicative bias in velocity, whether in the sensing system of the TPQ-27 or in the

software of the system, would result in an error increasing with time of fall and hence altitude. The accuracy of the velocity sensed by the TPQ-27 could be evaluated by comparison with FPS-16 data.

If the TPQ-27 incorrectly sensed the time of release and hence did not record the correct position of release, the bomb range discrepancy could be compensated for. However, in this case a constant time error would result in errors on the ground linear in aircraft velocity. This is not observed in figure 5, so it is unlikely that a time of release delay is the compensating factor.

Other possible sources of error deal with the software routines of the TPQ-27 systems. For example, there are 2 possible types of error that may be associated with the bomb range algorithm. The first is associated with incorrect values being input into the algorithm and the second is associated with exercising the algorithm. To investigate the accuracy of the bomb range algorithm, it was necessary to determine the values of the input data and the resulting computed bomb ranges for a variety of test conditions. These data were obtained by sampling from printouts of run records of the TPQ-27 CEP tests and consisted of the velocities and altitudes of the aircraft at times of release as sensed by the TPQ-27 and the corresponding calculated bomb ranges. It is the case that aircraft velocity at release was always less than test condition velocity, and altitude varied around test condition altitude. Thus, linear regression of bomb range on velocity and altitude was used to estimate the value of bomb range which would have been calculated, had exact test conditions been achieved. Since this estimation of bomb range is really an extrapolation, a certain amount of error is expected in the

estimate. However, the estimated bomb range derived from this analysis is, in all cases which were examined, closer to the NWL calculated bomb range for the ballistics used in the TPQ-27 CEP tests than it is to the revised bomb range established by NWL (see table 6). This then suggests, that, given the correct inputs, the TPQ-27 bomb range algorithm performed adequately. It is interesting to note, however, that the difference of +163 for test condition 9 is reflected in the G/C CEP test data: all the bombs dropped much shorter than expected, which suggests a larger bomb range calculation than appropriate.

A question remains concerning the adequacy of the inputs to the bomb range algorithm. For example, standard barometric conditions were used and no correction was made for deviation from standard. The extent to which such a correction would change calculated bomb range is probably small in most cases. A sensitivity analysis would have to be performed to determine the actual magnitude of the change for the days in which tests were performed. Another potentially faulty input to the bomb range algorithm is aircraft velocity. In the data examined, the recorded aircraft airspeed was <u>always</u> less than test condition specification velocity. An explanation for this phenomenon is that ground speed is maintained at test condition velocity and wind speed is subtracted to calculate air speed. However, air speed will be less than ground speed only when going with the wind. This is not the case in general when you have bomb runs made in generally opposite directions. If air speed were calculated incorrectly in the manner suggested, the effect of this error would be that when traveling with the wind the correct bomb range would be calculated and the bomb would hit the target. Alternatively, when the aircraft was going against the wind the air speed would be too slow

and the bomb range would be too short, so the bombs would fall long. This effect is not present in the CEP test data. One possible explanation for this is that the effect of the wind has been taken care of by the use of a pseudo-target and further adjustments for wind are not necessary. In this case, the use of an air speed less than the test condition speed in the bomb range algorithm would cause the bomb range to be shortened. Furthermore, the effect of such a reduction in speed will be translated to a distance on the ground which increases monotonically with increasing altitude. The effect would not necessarily be linear with altitude because the strength of the wind is not constant.

A final possible compensating software error is one of calculating the range from the aircraft to the pseudo-target. Such an error does not seem likely but the results of faulty range calculations could result in errors linear in altitude, which is supported by figure 4.

IV. CONCLUSIONS.

The following are conclusions with respect to both the ballistic calibration procedures and the characteristics of the AN/TPQ-27 system. Details to support these conclusions are contained in the body of the study.

- Instrumentation error in measuring observed bomb range is quite small when compared either to bomb dispersion or the discrepancy in bomb range. The effect of such instrumentation errors can be only to increase specified CEP.
- There is no statistical evidence within the ballistic calibration test data to suggest that the selected drag curve is not the correct one. Rather, analyses suggest that the selected drag curve gives an accurate representation of the ballistic characteristics of the bomb in question. As a result the true bomb range is very probably close to the calculated bomb range.
- Because of the relative insensitivity of specified CEP, and hence average CEP bombing ratio, to relatively large changes in bomb dispersions, the sample sizes used in the determination of bomb dispersion were adequate.
- Although there might be small errors in computing bomb range due to minor inaccuracies in the selected ballistic drag curve, the magnitude of these errors cannot account for the discrepancies suggested between the bomb ranges

derived from the revised ballistics and the ballistics used in the Government/Contractor CEP tests.

- Analysis of the Government/Contractor CEP test data give indication of the existence of errors in the TPQ-27 location of the aircraft. These errors however are predominately associated with alignment bias and not with range estimation. Since aircraft tracks were generally toward or away from the TPQ-27's location, these errors do not affect aircraft to target range and hence are not the cause of the bomb range discrepancy.
- Analysis of the TPQ-27's range and altitude errors in determining aircraft position in connection with impact range misses indicates that range and altitude sensing errors are not the source of the bomb discrepancy.
- The magnitude of bomb range error compensated for by the TPQ-27 system after adjusting for positional errors increases with test condition altitude.
- Of the possible system errors considered which might compensate for the bomb range discrepancy, the most likely is inappropriate determination of the initial velocity of the bomb at time of release.
- Other potential system errors are range to target computation, improper correction for barometric pressure differences from standard and errors in the operation of the bomb range algorithm.

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[b] OIC MCTSSA ltr 0122-3/TTB/lgn over 3960/3 00122-3A17973 of 18 July 1973.

APPENDIX

TABLE 1. Bomb Range Discrepancy Data

Test Condition Specification				Bomb Range G/C Tests	Bomb Range NWL BC Tests	BRD	Obs-comp Bomb Range in NWL BC Tests	$\overline{\Delta BR}$ = CBR^*-TBR from G/C Tests	BRD-$\overline{\Delta BR}$
				(1)	(2)	(3)=(2)-(1)	(4)	(5)	(6)=(3)-(5
#	VEL	ALT	Form Factor						
1	300	10,000	.7583	11432	11306	126	22	24	102
3	300	2,000	.7583	5364	5338	26	-6	12	14
9a	350	20,000	.7583	18231	17892	339	-27	-16	355
9b	350	20,000	.8389	17993	17892	101	-27	250	-134
9c	350	20,000	1.0000	17533	17892	-359	-27	-558	199
10	500	20,000	.8389	24189	23965	224	72	89	313
11	300	10,000	.7583	11432	11306	126	22	53	73
14	500	30,000	.8389	24189	23965	224	72	-15	239
17	500	20,000	.8389	29320	23972	343	33	79	255

TABLE 2a. Bomb Dispersion Estimates From Ballistic Calibration Tests

Test Condition Ballistic Calibration Tests		Contractor CEP Tests Condition Number	Bomb Dispersion Estimation Based on mean observed bomb range			Bomb Dispersion Estimation Based on computed bomb range			Bomb Dispersion Estimation Based on Median Radial Miss From Calcula
ALT(ft)	VEL(NM)		CEP (1)	d.f. (2)	90% CI on CEP (3)	CEP (4)	d.f. (5)	90% CI on CEP (6)	CEP (7)
2000	300	3	6.8*	9	4.1- 9.3	6.2	10	3.9- 8.4	10.5
2000	400	-	21.5	11	13.9-28.7	16.8	12	11.2-22.4	19.5
10000	300	1,11	47.2	21	35.1-58.8	45.7	22	34.2-56.3	44.1
10000	500	-	76.0	21	56.5-94.8	63.3	22	47.4-78.6	94.2
20000	350	9	66.9	17	47.8-85.2	66.8	18	48.3-84.7	64.3
20000	500	10,17	138.1	11	89.1-184.7	133.5	12	88.1-176.7	131.0
30000	400	-	106.1	15	73.8-136.9	101.6	16	71.7-130.3	119.8
30000	450	14**	134.3	7	74.7-190.4	122.9	8	71.8-171.1	134.7

* All bomb dispersion estimates are measured in the target plane in feet.

** 500 NM could not be attained at this altitude above ground level at the test range.

TABLE 2b. Observed Minus Calculated Bomb Range Values in Ballistic Calibration Tests

Test Condition Ballistic Calibration Tests		Contractor CEP Tests Condition Number	$\overline{\text{OBR-CBR}}$ From BC Tests	Standard Error of $\overline{\text{OBR-CBR}}$	t	Sample Size (n)	$t\sqrt{\frac{n-2}{2}}$
ALT(ft)	Vel (NM)	(1)	(2)	(3)	(4) = $\frac{(2)}{(3)}$	(5)	(6)
2000	300	3	-6.2*	2.87	-2.16	5	-1.67
2000	400	-	-2.7	7.50	- .36	6	- .29
10000	300	1,11	22.3	15.73	1.42	11	1.28
10000	500	-	26.2	26.56	.99	11	.90
20000	350	9	-27.2	21.03	-1.29	9	-1.14
20000	500	10,17	72.0	64.10	1.12	6	.91
30000	400	-	-49.3	26.13	- .19	8	- .16
30000	450**	14	33.3	80.02	.42	4	.30

* Data in columns (2) and (3) are measured in the target plane in feet

** 500 NM could not be attained at this altitude above ground level at the test range.

$\overline{X}$ = .02 for data in column (6)

S^2 = 1.08 for data in column (6)

TABLE 3. Data Base For G/C CEP Test Analysis

Test Condition	PMR Operation Number	Run Number	Total Number Runs	
1	214426	2,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19	16	
	214432	2	1	
	214268	3,6,7,12,13,16,17	7	
	214631	4,5,6,8,12	5	
	214637	5,10,12	3	
	215736	5,8,9,14,17,18,21,22,23,24,25,26,27,28	14	
	214426	20,21	2	
	214432	14,16,17,18,19,20,21,22,26,27	10	
	214904	5,9,10	3	
				61
3	215196	3,4,5,6,7,8,9,10,11,12,13,14	12	
	215334	4,5,6,7,8,9,11,12,14,15,16,18,19	13	
				25
9	214910	11,13,14,15,17,18 (Form Factor = .7583	6	
	215641	15,17,19,21,23,16,18,22,24 (Form Factor = .8389)	9	
	215641	7,9,10,11,13 (Form Factor - 1.000)	5	
				20
10	215861	3,4,5,7,8,9,10,11	8	
				8
11	215404	2,3,4,5,7,8,9,10,14,15,16,17,19,20,21,23,25,26	18	
	215510	11,17,18,20,21,22,23,24,25	9	
				27
14	319255	4,6,8,9,10,14,16,17	8	
	319261	2,3,5,7,9,11,13,14,15,16	10	
	319829	8,9,10,12,14,16,17	7	
	319832	9,12	2	
				27
17	319258	3,4,5,7,8	5	
	319264	3,4,5,6,8,9,10,11,12,13	12	
				17

TABLE 4. Data Summary; CEP Test Analysis

* All data in feet except $\Delta\theta$ which is in degrees

T.C.-DIR		n	$\overline{\Delta X}$ *	$\overline{\Delta Y}$	$\overline{\Delta Z}$	$\overline{\Delta R}$	$\overline{\Delta\theta}$	$\overline{IRM}$	$\overline{\Delta BR}$	SE($\overline{\Delta BR}$)
(.7583)										
1	In	31	- 14.7	- 35.6	23.1	16.0	-.19	- 22.3	25.7	
1	Out	30	- 4.0	3.5	18.2	6.9	-.01	- 25.3	22.2	
1	Both	61	- 9.5	- 16.4	20.7	11.5		- 23.8	24.3	8.4
(.7583)										
3	In	13	- 3.0	6.2	4.5	- 5.9	.03	- 35.2	23.3	
3	Out	12	8.9	10.4	4.9	- 4.0	-.17	- 10.7	0.2	
3	Both	25	2.7	8.2	4.7	- 5.0		- 23.4	12.2	7.1
(.7583)										
9	In	4	-111.0	31.7	260.0	116.2	-.12	- 58.7	56.2	
9	Out	2	-106.0	46.0	4.9	- 99.9	.18	57.78	-160.5	
9	Both	6	-109.3	36.5	175.0	44.17		- 19.87	- 16.03	66.6
(.8389)										
9	In	4	-151.0	- 61.5	311.6	104.7	-.34	-139.9	102.0	
9	Out	5	-162.8	+215.6	275.7	165.5	.81	-303.1	342.5	
9	Both	9	-157.6	92.4	291.6	138.3		-230.6	235.6	63.11
(1.000)										
9	In	1	- 95.0	- 62.0	290.5	84.4	-.22	418.0	-465.2	
9	Out	4	- 73.5	77.7	177.5	48.9	.37	549.6	-582.0	
9	Both	5	- 77.8	49.8	200.1	56.0		523.3	-558.6	32.04
(.8319)										
10	In	3	-135.3	- 78.3	279.0	109.7	.23	195.3	-261.1	
10	Out	5	- 63.6	92.0	205.5	69.5	-.24	- 73.7	14.0	
10	Both	8	- 90.5	28.1	233.0	84.6		27.1	- 89.2	69.7
(.7583)										
11	In	10	-131.4	34.7	- 15.4	- 12.0	.53	- 54.8	50.9	
11	Out	17	- 97.0	22.8	- 15.0	- 18.2	-.64	- 63.6	53.6	
11	Both	27	-109.8	27.8	- 15.5	- 16.0		- 60.3	52.6	11.6
(.8389)										
14	In	2	-170.5	14.5	-183.2	163.7	.15	476.0	-229.1	
14	Out	25	-149.3	-137.5	- 86.0	3.5	-.51	-62.2	104.7	
14	Both	27	-150.8	-126.2	- 93.2	15.3		21.7	79.3	86.2
(.8389)										
17	In	6	-215.0	-100.0	-113.7	175.0	.35	189.7	56.8	
17	Out	11	-192.2	-166.5	- 42.1	17.6	-.62	98.1	- 54.0	
17	Both	17	-200.2	-143.0	- 67.4	73.2		130.4	- 14.8	50.2

TABLE 5. Altitude Correction Factor

Test Condition			K
#	VEL	ALT	
1,11	300	10,000	.546
3	300	2,000	1.303
9	350	20,000	.457
10,17	500	20,000	.629
14	500	30,000	.454

TABLE 6. G/C Test Bomb Range Comparison Data

Test Condition			Test Condition Bomb Range Utilized in TPQ-27 Tests as Calculated by NWL	Test Condtion Bomb Range Utilized in TPQ-27 Tests as Calculated by Regression on Tests Results	Difference
9	350	20,000	17,993	18,156	+163
10	500	20,000	24,189	24,168	- 21
1,11	300	10,000	11,432	11,412	- 20
14	500	30,000	29,320	29,192	-128

TABLE 7. CEP Bomb Ratio Calculation Based on Hypothetical Error in Estimating Bomb Dispersion

			Using Data Adjusted for Bomb Range			
Test Condition	Revised Specified CEP	CEP Utilizing Upper 90% CI Limit on Bomb Dispersion	CEP Bombing Ratio		CEP Bombing Ratio Using 90% CI Limit on Bomb Dispersion	
1	24.39	26.26	.68	.67	.73	.73
1	22.20	24.24	.65		.71	
3	17.03	17.09	1.41		1.41	
9	46.78	48.90	.60	.80	.63	.84
9	47.96	50.03	.84		.88	
10	69.92	76.28	1.00		1.09	
11	40.57	41.72	.79		.81	
14	82.60	91.28	.43		.48	
17	78.83	83.21	.52		.55	
		Average	.80		.84	

TABLE 8. Partitioning of Revised Specified CEP into Bomb Dispersion and "Other" Dispersion Component.

Test Condition	Revised Specified $(CEP)^2$	=	Bomb Dispersion Squared	+	Other Budgeted Dispersion Squared	Ratio $\left(\frac{\text{Bomb Dispersion}}{\text{CEP}}\right)^2$
1	595		197		389	.33
1	493		197		296	.39
3	290		5		285	.02
9	2188		468		1720	.21
9	2300		468		1831	.20
10	4888		1980		2908	.41
11	1646		197		1449	.12
14	6823		1207		5615	.18
17	6214		2007		4206	.32

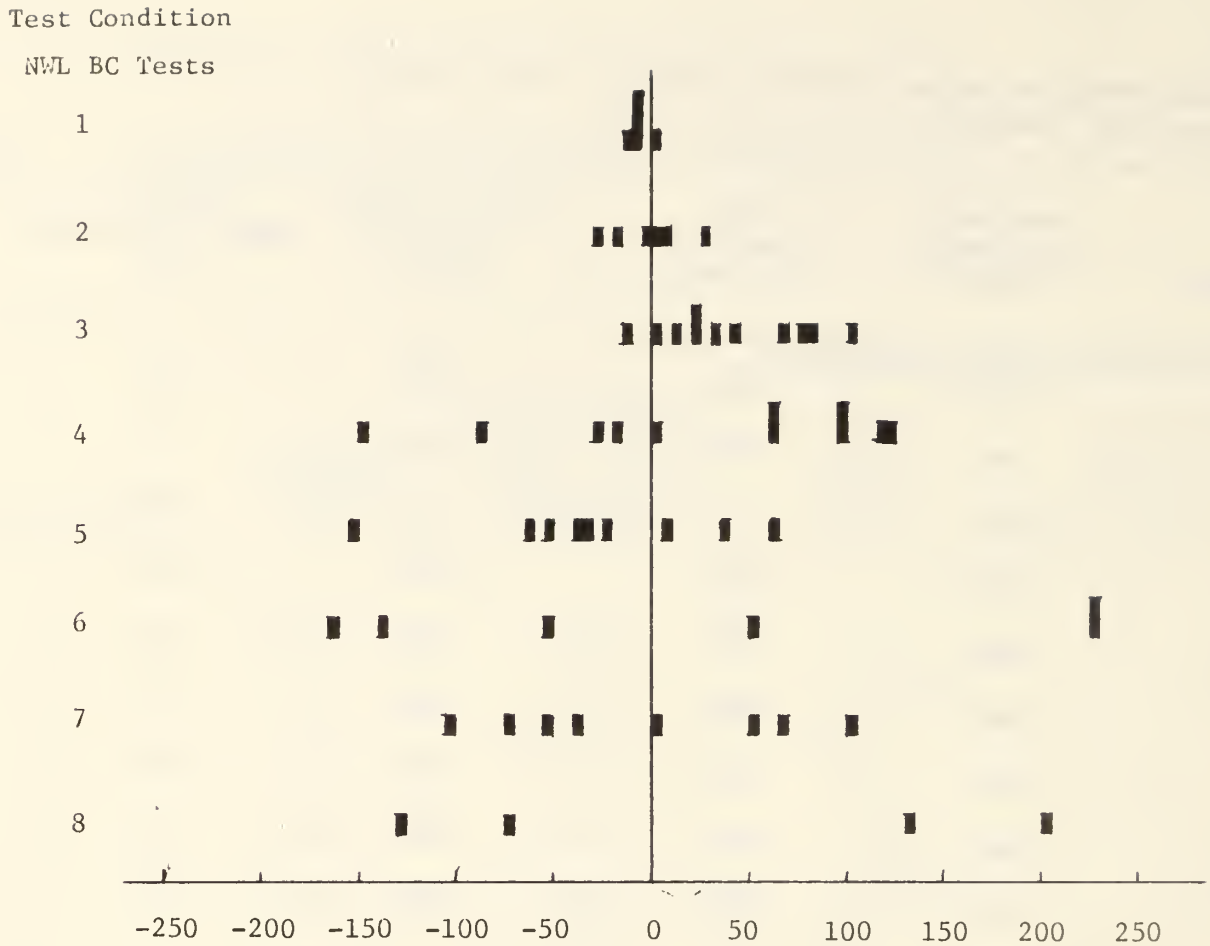

FIGURE 1. Observed Minus Computed Bomb Ranges for Ballistic Computation Test Data Corresponding to Revised Ballistic Drag Curve. (ft)

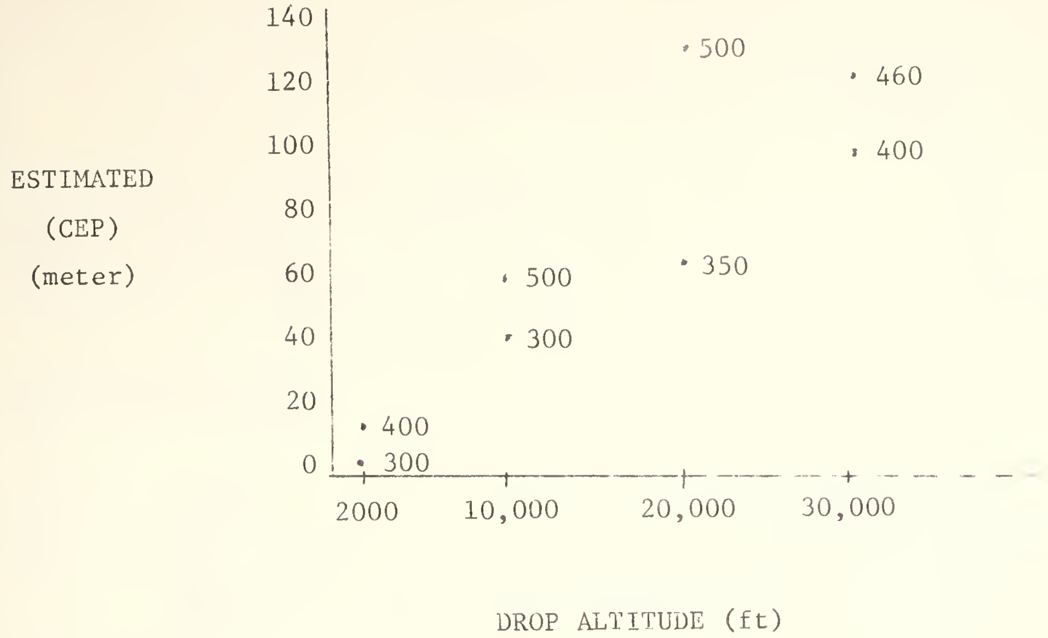

FIGURE 2. Estimated CEP as a Function of Drop Altitude and Velocity

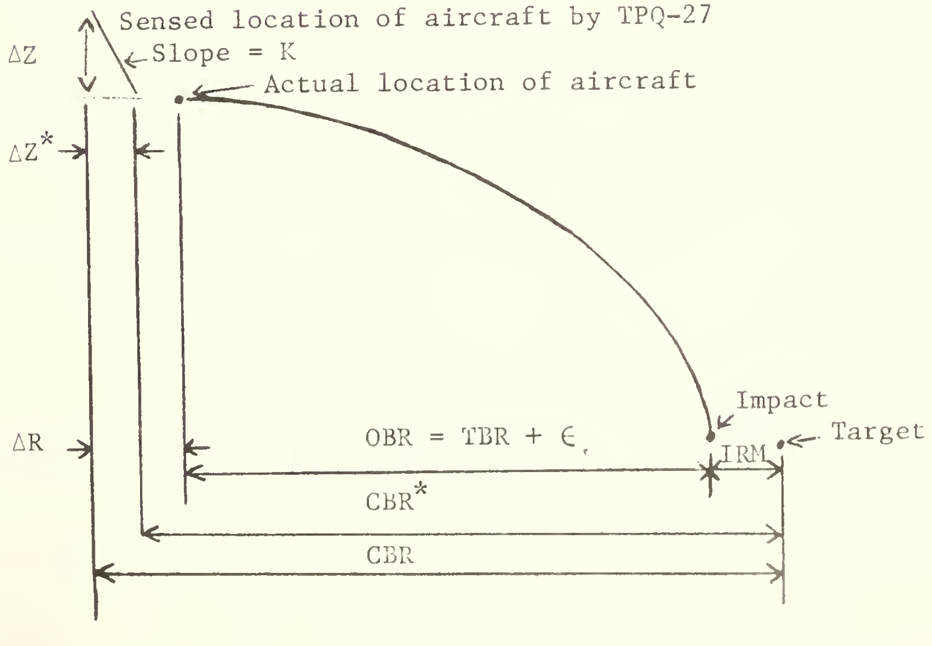

FIGURE 3. Schematic of Result of Typical Bomb Drop

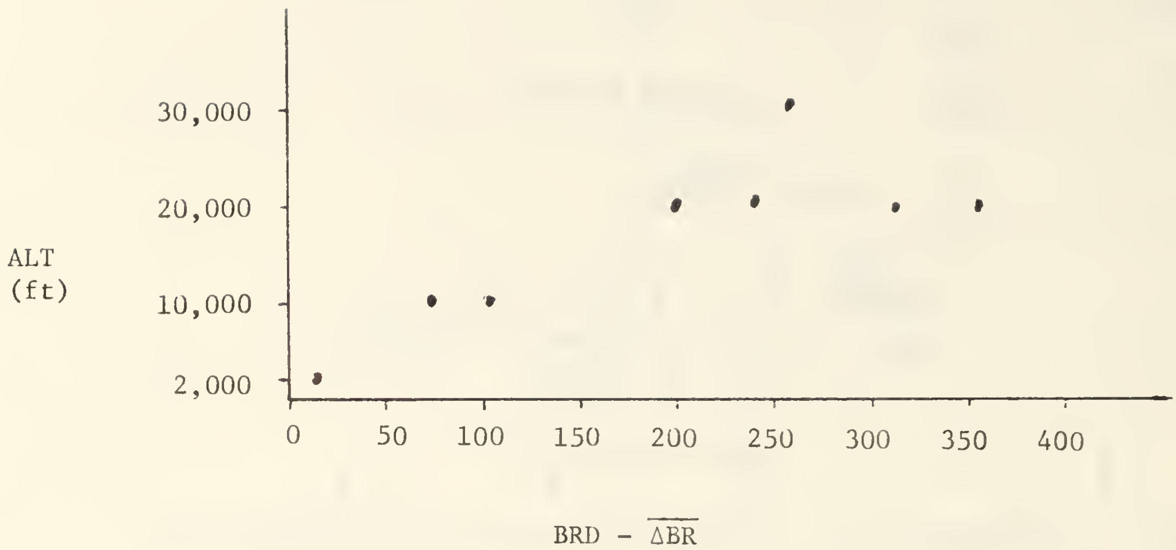

FIGURE 4. Bomb Range Discrepancy as a Function of Drop Altitude

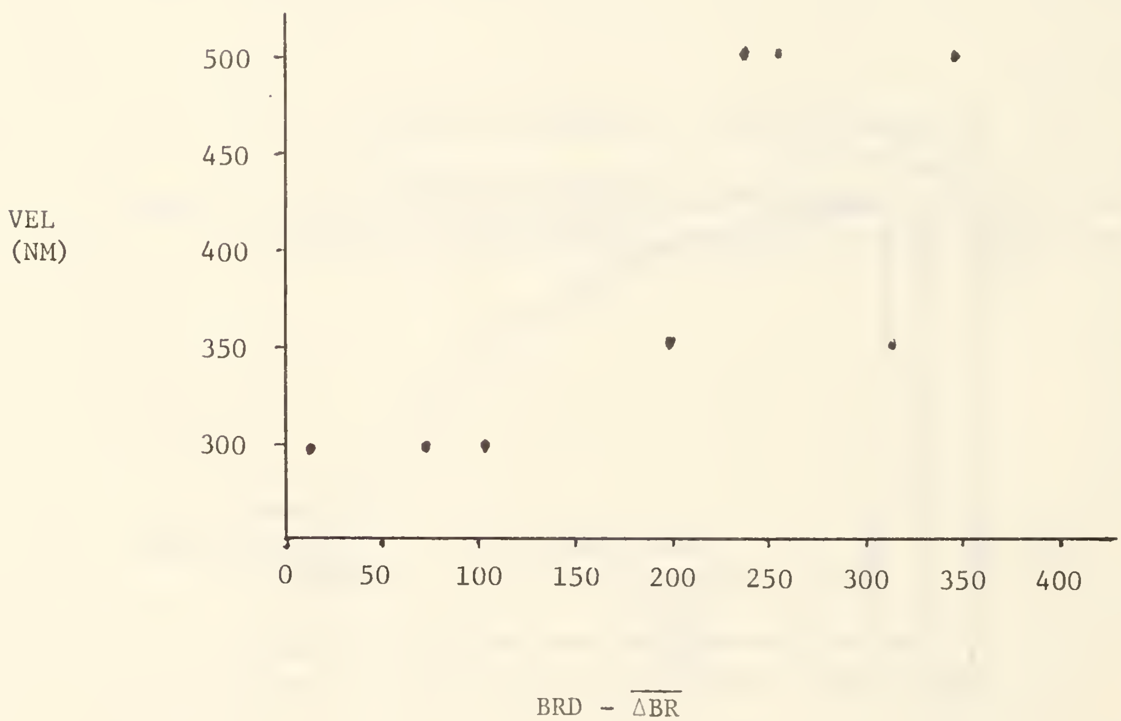

FIGURE 5. Bomb Range Discrepancy as a Function of Drop Velocity

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